121. Gelatinous substance of Rolando in the centre of which is seen the central canal of the spinal cord.
122. The central canal.
123. The ventral horns of the spinal cord in connection with the efferent or motor fibres.
124. The dorsal horns in connection with the afferent or sensory fibres.
125. The central gray matter of the spinal cord.
126. Claustrum, claustrum, avant-mur, vormauer—lying between the lenticulate nucleus and the gyri of the island.
127. Antero-posterior fasciculus composed of afferent fibres, *a*, *a*, *a*, and of efferent fibres, *c*, *c*, *c*, which form the connection between the anterior gyri of the cerebral lobes and the most distant part of the corpus striatum and the thalamus, and which form a kind of enclosure in which the claustrum lies (connections those of Luys).
128. Inter-cortical commissural fibres—association fibres of Meynert.
129. Ventral column of the spinal cord separating from that of the opposite side to allow the lateral columns to decussate.
130. The decussation of the pyramids.
131. The decussation of the dorsal columns.
132. The ventral pyramids.
133. Substantia nigra lying between the two fasciculi which form the anterior pyramids.
134. The ventral layer of the cerebral peduncle—crusta, crusta, *F*—, Hirnschenkelfuss.
135. The superior layer of the cerebral peduncle formed by the dorsal and ventral columns of the spinal cord.

A LABORATORY COURSE IN PHYSIOLOGICAL PSYCHOLOGY.

By Edmund C. Sanford, Ph. D.

After Prof. Ladd's careful statement of the psycho-physiological facts and Prof. James's brilliant exposition of their psychological and even metaphysical import, it is no longer necessary to argue the importance of the subject matter of this branch of the new psychology. No one that has once seen the new is going to be satisfied any longer with the old. But the appropriation of new facts alone is not sufficient to elevate psychology to its true place in the circle of sciences. As long as psychologists live upon the crumbs that fall from the tables of neurology and physiology they will live in dependence. They must investigate for themselves,—no less rigorously and no less broad-mindedly than others, but from their own standpoint, and must view what they find in its psychological perspective. This means that a prominent place must be given to psychological laboratories for research; and the friends of psychology already congratulate themselves on the beginning of several of great promise in this country.

Beyond this, however, lies another thing of cardinal importance, namely, the adoption of a right pedagogical method. The student of psychology must have its facts and principles brought home to him in a way not inferior to the best in other sciences, if psychology is to have the infusion of new vigor that they have had, and afford the healthy and virile training that they afford. He must see for himself the phenomena about which he psychologizes, he must perform the experiments, he must have the inside view. The new psychology has been said to do away with introspection, but that is a mistake. It retains in-

trospection and refines and gives it precision by making it operate under experimental conditions; and it is just these inner aspects that are particularly hard for the student to frame for himself from bare descriptions. He must himself serve as subject of the experiment before he can really understand it. To say, as has recently been said, that a few models of the brain and a color-mixer are about all the apparatus needed for a course in physiological psychology savors of the scholasticism from which we hope to have escaped. Notwithstanding its better material, such a method must lead to the same text-book work and the same artificial general conceptions as of old. For those especially that are to work in any of the fields of applied psychology, in pedagogy, or criminology, or even theology, the intimate laboratory knowledge (and its parallels in anthropological and comparative psychology) is essential to an effective grasp of their subjects. The need of such an apprenticeship for later work in the research laboratory is of course obvious. That such a course is even now desired by open eyed teachers is shown by the inquiries made for it of those known to be engaged in experimental psychological work.

Just what experiments such a course should contain is itself as yet a matter of experiment; but that it should, if it aims at any thing like proportion, introduce the student to all the chief methods of research and cause him to observe for himself all the more important phenomena seems reasonable. Such a course has been in mind in the collection of the experiments which is begun below, and which is to be continued in successive numbers of the JOURNAL till completed. That the list is complete or the selection always the best the author is very far from maintaining — to mention a large omission only, no experiments on hypnotism are now proposed, because they seem unfitted to beginners in the field. And in any event the ideal laboratory course can only be reached after repeated adaptation and long trial in actual use. This course had its origin in a series of notes which it was found necessary to make for the use of a group of students taking my practice course during the past year. The experiments have been performed in the laboratory here, and all, except those added in this revision, by the students themselves. The demonstrational character of the work has been kept in mind, and the experiments chosen are generally rather qualitative than quantitative, even where for convenience they have been given a quantitative form. In selecting apparatus the simplest that promised the desired result has generally been chosen; and while this makes the course by no means representative of the facilities of this laboratory, much less of the possibilities of psychological experimentation, it may perhaps make it useful to those teachers—unfortunately too many—whose equipment must be brought within the compass of a scanty appropriation. A large part of the absolutely essential apparatus could be made by the teacher himself, and almost all, I doubt not, with the assistance of common mechanics. The notes on apparatus and references to literature that are inserted from time to time will open the way to more elaborate experiments and apparatus for those that desire them.

I.—THE DERMAL SENSES.

SENSATIONS OF CONTACT.

Apparatus. The experiments on the Sense of Locality require no special apparatus. Those on Discriminative Sensibility can be made with ordinary drawing dividers; but if these are used, it will be well to stick the points into little pointed tips of cork to avoid the sharpness and coldness of the metal. (An excellent, but more expensive, Æsthesiometer is made by C. Verdin, 7 Rue Linne, Paris, at 35 francs; for the description of an elaborate and very convenient one, see AMER. JOUR.

PSYCHOL. I, 552.) Something is also needed in experiment 6 *d* for rendering the skin anæsthesic.

1. The Sense of Locality. Touch yourself in several places with the same object, and analyze out, as far as you can, the particular quality of the sensation by which you recognize the place touched. This quality of the sensation is known as the "Local Sign."

2. Cause the subject to close his eyes; touch him on the fore-arm with a pencil point; and require him to touch the same point with another pencil immediately afterward. Estimate the error in millimeters and average the results for a number of trials, noting the direction of error, if it is constant. The subject may be allowed to correct his placing of the pencil if not satisfied with it on first contact.

3. Aristotle's Experiment. Cross the middle finger over the first in such a way as to bring the tip of the middle finger on the thumb side of the first finger. Insert between the two a pea or other small object. A more or less distinct sensation, of *two* objects will result, especially when the fingers are moved.

4. Judgments of Motion on the Skin. *a.* Subject with closed eyes. Resting a pencil point or the head of a pin gently on the fore-arm, move it slowly and evenly up or down the arm. Require the subject to indicate his earliest judgment of the direction. If the experiment is carefully made, the fact of motion will be perceived before its direction. *b.* Try a number of times, estimating the distances traversed in millimeters and averaging for the two directions separately. It will probably be found that the downward distances have been greater than the upward. *c.* Starting from a fixed point on the fore-arm move the pencil in irregular order up, down, right or left, and require the subject to announce the direction of motion as before.

Cf. Hall and Donaldson, Motor Sensations of the Skin; Mind, X, 1885, 557.

5. Rest the fingers lightly on the forehead and move the head from side to side keeping the fingers motionless. Almost the whole of the motion will be attributed to the fingers. Light tapping of the forehead with the finger we feel in the forehead more markedly than in the finger. With our own hand on our forehead we feel the forehead; with some one else's hand we feel the hand.

6. Weber's Sensory Circles. *a.* Find the least distance apart at which the points of the æsthesiometric compasses can be recognized as two when applied to the skin of the fore-arm. Try also the upper arm, the back of the hand, the forehead, the finger-tip and the tip of the tongue. Be very careful to put both points on the skin at the same time and to bear on equally with both. *b.* Compare the distance between the points just recognizable as two when applied lengthwise of the arm with that found when they are applied crosswise. *c.* Give the points a slightly less separation than that found for the fore-arm (crosswise) and beginning at the elbow draw the points downward side by side along the arm. They will at first appear as one, later as two, after which they will appear to separate as they descend. Something similar will be found on drawing the points from side to side across the face so that one shall go above, the other below the mouth. *d.* Make the skin anæsthesic with an ether spray and test the discriminative sensibility as before.

Cf. Weber's measurements as given in the text-books.

7. Filled space is relatively under-estimated by the skin. Set up in a small wooden rod a row of five pins separated by intervals of half an inch, and in another two pins an inch and a half apart. Apply to the arm like the compasses above. The space occupied by the five pins will seem less than that between the two.

8. Active touch, that is touch with movement, is far more discriminating than mere contact. Compare the sensations received from resting the tip of the finger on a rough covered book with those received when the finger is moved and the surface "felt of."

9. The time discriminations of the sense of contact are very delicate. Strike a tuning-fork, touch it near the bottom of the prong and immediately remove the finger so as not to stop the fork. The taps of the fork on the skin do not blend into a continuous sensation for the tactual sense, even when the vibrations are 1000 or more a second.

For sensations of minimal contact, see Ex. 22.

On the foregoing experiments, cf. Weber, Tastsinn und Gemeingefühl, Wagner's Handwörterbuch der Physiologie, Vol. III, pt. 2; Funke, Hermann's Handbuch der Physiologie, Vol. III, pt. 2.

SENSATIONS OF TEMPERATURE.

Apparatus. Two brass rods (6 inches long and 0.25 inch in diameter, turned down to a fine smooth point 0.5 mm. in diameter), paper ruled in mm. squares, menthol pencil (such as is used for headaches), centigrade thermometers, vessels of water at different temperatures.

10. Hot and Cold Spots. *a.* Move one of the pointed brass rods, or even a cool lead pencil slowly and lightly over the skin of the back of the hand. At certain points distinct sensations of cold will flash out, while at others no temperature sensation will be perceived, or at most, only a faint and diffuse one. Heat one of the rods and repeat the experiment. *b.* On some convenient portion of the skin mark off the corners of a square 2 cm. on the side. Go over this square carefully both lengthwise and crosswise for both heat and cold, drawing the point along lines 1 mm. apart, and note on a corresponding square of millimeter paper the hot and cold spots found, hot spots with red ink, cold with black. This time the points should be heated or cooled considerably by placing them in vessels of hot or cold water and should be kept at an approximately constant temperature by frequent change, one being left in the water while the other is in use. Break the experiment into a number of sittings so as to avoid fatiguing the spots; for they are very readily fatigued. A map made in this way cannot hope to represent all the spots, but it will suffice to show the permanence of some of them and possibly to show their general arrangement. *c.* Notice the very distinct persistence of the sensations after the point has been removed.

11. The temperature spots respond with their characteristic sensations to mechanical (and electrical) stimulation, and do not give pain when punctured. *a.* Choose a very certainly located cold spot and tap it gently with a fine wooden point (not too soon after locating it, if it has been fatigued in locating); or better have an assistant tap it. *b.* Thrust a needle into a well located cold point. Try both for comparison on an adjacent portion of the skin.

12. The temperature spots respond to chemical stimulation. Choose a convenient area, say on the back of the hand, and take its temperature carefully, allowing the thermometer to remain in contact with the skin as long as it continues to rise. Note the temperature and rub the skin lightly with a menthol pencil. After a little the sensation of cold will appear. Take the temperature of the skin again; it will be found as high or higher than before, in spite of the contrary sensation. The menthol makes the nerves of cold at first hyperæsthesic (so that they respond with their specific sensation to mere contact, and give an intenser sensation when a cold body is applied than do adjacent normal portions of the skin); afterward, however, all the cutaneous nerves become more or less anæsthesic.

Cf. on the foregoing experiments: Blix, Zeitschrift für Biologie, Bd. XX, H. 2. 1884. Goldscheider, Neue Thatsachen über die Hautsinnesnerven, Du Bois-Reymond's Archiv, Supplement-Band, 1885, pp. 1-110; Donaldson, On the Temperature-sense, Mind, X, 1885; and the literature cited by these authors. On the chemical stimulation of the temperature nerves: (Cold) Goldscheider, Ueber die specifische Wirkung des Menthols auf die Temperatur-Nerven, Verh. d. Berliner physiol. Gesell. 9 April, 1886, Du Bois-Reymond's Archiv, 1886, p. 555; (heat) Die einwirkung der Kohlensäure auf die sensiblen Nerven des Haut, Verh. d. Berliner physiol. Gesell. 25, Nov. 1887, Du Bois-Reymond's Archiv, 1888.

13. The temperature of the skin at any moment is a balance between its gain and loss of heat. Anything that disturbs that balance, causing increased gain or loss of heat, produces temperature sensations. It is common experience that a piece of cloth, a bit of wood, a piece of metal, all of the same temperature as the air that seems indifferent to the hand, cause different degrees of the sensation of cold when touched, because they increase the loss of heat by conduction in different degrees. If a paper bag be placed over the hand held upward, a sensation of warmth is soon felt, because of the decreased loss of heat.

14. Provide three vessels of water one at 30° c., the second at 40°, the third at 20°. Put a finger of one hand into the warmer water, a finger of the other into the cooler. At first the usual temperature sensations will be felt, but after a little they disappear more or less completely, because of the fatigue of the corresponding temperature organs. Now transfer both fingers to the water of normal temperature. It will seem cool to the finger from warmer water and warm to the one from cooler.

15. The intensity of the temperature sensation depends on the amount of surface stimulated. Dip a finger in cold water, then the whole hand. Notice the increase in sensation.

16. The fatigue of the temperature apparatus may produce an apparent contradiction of Ex. 15. Dip one hand entirely under cold water and keep it there for a moment. Then dip the finger of the other hand or the whole hand several times in the same water, withdrawing it immediately each time. The water seems colder to the finger or hand which is only dipped.

17. Hold a very cold piece of metal on the forehead or on the palm of the hand for half a minute. On removing it the sensation of cold continues though the actual temperature of the skin is rising. Sometimes fluctuations are observed in the persisting sensation. After contact with a hot body the sensation of heat continues in the same way, though the temperature of the skin falls. Goldscheider explains this result for cold in part by the persistence of the cold sensation in the manner of an after-image, and in part by the lessened sensibility of the nerves of heat; a similar explanation *mutatis mutandis* holds also for heat.

18. Extreme temperatures fatigue the sensory apparatus of both heat and cold. *a*. Hold a finger in water of 45° c., the corresponding finger of the other hand in water which feels neither cold nor hot (about 32°). After 10 seconds dip them alternately into water at 10°. The finger from the water at 32° will feel the cold more strongly. *b*. Hold a finger in water at 10°, the corresponding finger of the other hand in water at 32°. After 10 seconds dip them alternately in water at 45°. The finger from the water at 32° will feel the heat more strongly.

19. Hold the hand for one minute in water of 12° c., then transfer it to water of 18°. The latter will at first feel warm, but after a time cold again. The water at 18° first causes a decrease in the loss of heat or a slight gain but later a continued loss.

20. Fineness of temperature discrimination. *a*. Find what is the least perceptible difference in temperature between two vessels of water

at about 30° c., at about 0°, and about 55°. The finest discrimination will probably be found with the first temperature, if the discrimination does not prove too fine at all these points to be measured with the thermometers at hand. Use the same hand for these tests, always dipping it to the same depth. It is better to dip the hand repeatedly than to keep it in the water. *b*. The different surfaces of the body vary much in their sensitiveness to temperature. The mucous surfaces are quite obtuse. When drinking a comfortably hot cup of coffee, dip the upper lip into it so that the coffee touches the skin above the red part of the lip, or dip the finger into it; it will seem burning hot. Plunge the hand into water at 5–10° c. The sensation of cold will be strongest at first on the back of the hand where the skin is thin, but a little later will come out more strongly in the palm, where it will continue to be stronger as it approaches pain.

On these general temperature experiments cf. the works of Weber and Goldscheider already cited, also Hering, in Hermann's Handbuch der Physiologie, Vol. III, pt. 2, pp. 415-439. Fechner, Elemente der Psychophysik, Vol. II, pp. 201-211.

SENSATIONS OF PRESSURE.

Apparatus. Bits of cork. Weights for minimal pressure. (These can be cut from rectangular prisms of cork or elder-pith of equal area, and provided with bristle or hair handles and verified upon a sensitive balance. The prism should be from 3 to 5 mm. square. The handle is made by setting the ends of a piece of bristle or hair into opposite sides of the bits of cork or elder-pith, thus giving the whole something the shape of a seal ring, of which the cork is the seal and the bristle the band. A series ranging from 0.002 to 0.02 grams would be convenient; but for the experiment to follow is not necessary.) Two objects of equal weight, but unequal size; a large cork and a small one, made of equal weight by loading the smaller with shot, answer very well. Two metal disks of equal size and weight, *e. g.* dollar pieces; and two wooden cylinders three quarters of an inch in diameter and one inch long. Vessels of water at normal temperature. Weights for discriminative sensibility. (The last can readily be made by loading paper gun-shells with shot. The following would be a convenient series: One hundred grams (two of this weight), 102.5, 103.3, 104, 105, 106, 107. The Cambridge Scientific Instrument Co., St. Tibb's Row, Cambridge, England, manufactures a set, which can also be used for "muscle-sense" tests, containing 30 weights and giving ratios ranging from about one-fourth to one fiftieth, at a price of £5.)

On apparatus for sensations of pressure cf. Beaunis, Éléments de physiologie humaine, II, 579. Eulenberg, Berlin. klin. Wochensch. 1869, No. 44. (See illustration and description of Eulenberg's instrument in the Reference Hand-book of the Medical Sciences, Vol. I, p. 85.) Dorhn, Zeitschr. f. rat. med., 3 R., X, 337. Bastelberger, Experimentelle Prüfung der zur Drucksinn-Messung angewandten Methoden, Stuttgart, 1879. Jastrow gives in the American Journal of Psychology, II, 54, a very inadequate description of a very satisfactory instrument. See also notes on apparatus for the study of the Psychophysic Law to be given later.

21. Pressure points. Make an obtuse but extremely fine cork point (pyramidal in shape, for example, the pyramid a quarter of an inch square on the base and of equal height), set it upon the point of a pen or other convenient holder, or use a match whittled down to a fine point, or even a needle. Choose an area on the forearm and test for its pressure spots somewhat as for the hot and cold spots, but this time set the cork point as lightly as possible on point after point of the skin instead of drawing it along. Two kinds of sensation will be felt; at some points a clear feeling of contact with a sharp point will be felt, at others no feeling at all or a dull and vacuous one. The first are the pressure points. Goldscheider describes their sensations on light contact as "delicate," "lively," "somewhat tickling * * * as from moving a hair;" on stronger pressure, "as if there was a resistance at that point

in the skin, which worked against the pressure stimulus;" "as if a small hard kernel lay there and was pressed down into the skin."

The first are more sensitive to small changes of pressure, and, though with sufficient increase both give pain, their sensations retain their characteristics. They are closer together than the temperature spots, and harder to locate; and the fact that our most frequent sensations of pressure are from surfaces and not from points makes it difficult at first to recognize a pressure quality in their sensations.

Cf. Goldscheider, Neue Thatsachen über die Hautsinnesnerven. DuBois-Reymond's Archiv, 1885, Supplement Band, pp. 76-84.

22. Minimal pressure (or simple contact). Make weights that are just perceivable on the volar side of the fore-arm and on the tips of the fingers. Try also if convenient the temples, forehead and eye-lids. In applying the weights see that they are brought down slowly upon the surface of the skin, that they touch equally at all points, and that their presence is not betrayed by motion of the weight after it touches the skin. This can be done by using a pen-holder or small rod, with its tip put through the ring of the weight, for laying it on. Compare the relative sensibility found by this method with that found with Weber's compasses for the same parts, and note that the latter requires discrimination, not mere perception. The stimulus needed to produce this faintest sensation is known as the stimulus of the "Initial Threshold." See also experiment 28.

Cf. Aubert and Kammler, Moleschott's Untersuchungen, V, 145.

23. Relation of apparent weight to area of surface stimulated. Test with the equal weights of unequal size. The smaller will seem decidedly heavier.

24. Discriminative sensibility for pressures. Have the subject lay his hand, palm upward, on such a support as will bring his arm into a comfortable position and make his palm level, for example a folded towel on a low table or the seat of a chair. (The matter of an easy position for the subject is of cardinal importance in all psychological experiment, and is mentioned here once for all.) Lay in his palm a piece of blotting paper just large enough to prevent the weight from touching the skin. On this set a standard weight, *e. g.* 100 grams, and after a couple of seconds replace it with an equal weight, or one heavier (or one lighter) *e. g.* 106 grams, allowing that to remain an equal time. Require the subject to say whether the second weight is the same or heavier, (or lighter, if a lighter is being used). Find the weight that can be distinguished from the standard in 75 per cent. of the trials. The ratio between the difference of these and the standard is the index of the sensibility. The ratio will probably be about 5 : 100. It is best not to use both a lighter and a heavier in the same series; and with this method of testing the subject should always guess, if he cannot discriminate. Be careful in putting on the weights that the subject does not recognize a difference in the force with which they strike, also that suggestions by difference of temperature or by sounds made in selecting the weights are avoided. This method of determining sensibility is known as the "Method of Right and Wrong Cases." Cf. later experiments on the Psychophysic Law.

25. Cold or hot bodies feel heavier than bodies of equal weight at a normal temperature. *a.* For cold, take two dollar pieces, warm one until it ceases to seem cold; cool the other to 10° c. Apply alternately to the palm of the hand. The cold one will seem much heavier, perhaps as heavy as two at the normal temperature. *b.* For heat, take two wooden cylinders of equal weight, heat one to a high temperature by standing it on end in a metal vessel floating in a water bath. Apply the cylinders on end alternately to the back of the hand between the metacarpal bones of the thumb and first finger. The hot one will seem heavier.

26. Pressure evenly distributed over a considerable area is less strongly felt than pressure upon an area bordered by one that is not pressed. Dip the hand up to the wrist into water (or better still into mercury) of normal temperature and notice that the sensation of pressure is strongest in a ring about the wrist at the surface of the water, possibly stronger on the volar than on the dorsal side. The ring effect is unmistakable when the hand is moved up and down in the water.

27. Something of the refinement of the pressure sense in perceiving the unevenness of surfaces may be seen by laying a hair on a plate of glass or other hard, smooth surface and over it 10 or 15 sheets of writing paper. The position of the hair can easily be felt by passing the finger tips back and forth over the surface.

28. Something might be said in support of the hairs as independent sense organs. The finest respond with a distinct sensation of anticipatory touch, as it were, when they are moved, and probably this accounts for a part at least of the differences between the fore-arm and finger tips found in Ex. 21. Touch a few single hairs and observe the sensation.

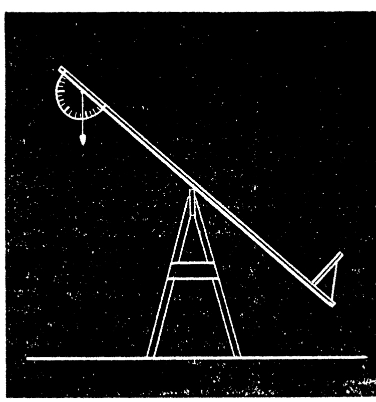
Cf. Blaschko, Zur Lehre von den Druckempfindungen. Verhandl, d. Berliner physiol. Gesell. Sitz, 27 März, 1885, DuBois-Reymond's Archiv, 1885, p. 349.

On the general topic cf. Weber, *op. cit.*; Funke, Tastsinn und Gemeingefühl, Hermann's Handbuch der Physiol., Vol. III, pt. 2, pp. 289-414.

II.—STATIC AND KINÆSTHESIC SENSES.

This group of senses furnishes us with data respecting the positions and motions of our members, and of our bodies as wholes. It includes senses whose existence or efficiency is disputed *e. g.* (Innervation Sense and Muscle Sense) and others whose independence has lately been asserted (*e. g.* Joint Sense and Tendon Sense.) This embarrasses somewhat the selection of experiments, but those chosen are the ones that seem at present characteristic. Many of the weightiest psychological inferences depend upon the sensations of motion and position of the eyes. It seems best, however, to postpone the experiments upon these sensations to the section upon vision.

Recognition of the Position of the Body as a Whole.



Apparatus. A light wooden rod a yard long; a tilting board and straps. For the last a board seven feet long and 18 inches wide balanced across a saw-horse will answer. At one end a foot board should be fastened securely enough to bear the weight of a man when the board is in a vertical position. At the other end a plumb line and semicircular scale should be added so that the inclination of the board can be read off at any instant. For holding the subject securely upon the board when its inclination is considerable, and the subject is head downward it will be necessary to have a couple of shoulder straps passing over the subject's shoulders and fastening to stout screw-eyes screwed into the board itself or into the foot board, and perhaps a breast strap going about both the subject and the board.

Cf. Aubert, Physiologische Studien über die Orientierung, (translation with comments of Delage's Études expérimentales sur les illusions statiques et dynamiques de direction, etc.,) Tübingen, 1888, p. 41.

29. In this experiment it is especially desirable that the subject should know as little as possible of the purpose of the experiment. Cause the subject to stand erect with his back against a wall. Choose a point on the opposite wall about the height of his shoulders. Let him look at it, and then require him, having closed his eyes, to point to it as exactly as possibly with a light rod held symmetrically in both hands. Cause him also to hold the rod vertically and horizontally in the median plane; also horizontally parallel to the frontal plane. All these he will probably be able to do with much accuracy, or if, as sometimes happens, he shows a "personal equation," his error will be constant.

30. *a*. Cause the subject to repeat the experiment, this time turning his head well to the left after closing his eyes. Repeat, causing the subject to turn to the right. In both cases an error of about 15° will be observed, the subject pointing too far by that amount in the direction opposite to that of the turning of the head. The subject will be able to hold the rod vertical or horizontal without error. *b*. Cause the subject to hold the rod in what he thinks is a horizontal position in the median plane, when his head is thrown well back; when bowed well forward. Illusions like those observed above will result. *c*. Cause the subject to hold the rod in what he thinks is a horizontal position, parallel to the frontal plane, when his head is leaned to the right; when leaned to the left. Illusions similar to those in the previous experiments will appear. *d*. Repeat experiment *a*, but instead of having the subject point to the designated object, have him walk toward it keeping his shoulders square, his eyes shut, and his head turned to one side. He will walk more and more too far toward the side away from which his head is turned. In all these cases judgment of one cardinal direction in space alone is affected, the other two show little or no errors.

31. After some practice and with attention to the sensations, the illusion of Ex. 30 takes another form, namely, that the body has turned a few degrees in the same direction as the head. The subject can now point to the chosen object; but, if required to set the end of the rod against his breast so that it shall be horizontal and perpendicular to the line joining his shoulders, he will make an error of about 15° in the direction of the motion of the head. A similar illusion may be found for the other directions of head turning, if tried under proper conditions *e. g.* when hanging by the hands with the arms somewhat bent.

32. The illusion is due, at least in cases *a* and *b* Ex. 30, to sensations of the position of the eyes. As may easily be observed upon any other person, the eyes turn further than the head in the direction in which it is turned. From the eyes we judge the position of the head, and thus overjudging it, point too far in a contrary direction in trying to point to the required object. The illusions can be produced by motion of the eyes alone. *a*. Holding the head erect and taking pains not to move it when moving the eyes, turn the closed eyes as far as possible to the right or left and then try to point to some determined object. An error like that in Ex. 30 will be observed. Turning of the eyes upward or downward has a less satisfactory result. Instead of closing the eyes they may be kept open if an opaque screen is held close before the face. *b*. Repeat *a* and *b* of Ex. 30, voluntarily turning the eyes as far as possible in the direction opposite to that of the turning of the head. The original error will disappear or be found to have changed its sign.

33. Another set of illusions regarding the position of the body as a whole in space depend in large measure on the distribution of pressure on the surfaces of the body, the direction of pressure of the movable viscera and the blood. Secure the subject properly upon the tilting board, and have him close his eyes. Start with the board vertical, (head up).

The subject will probably announce that he is then leaning forward slightly. Turn him slowly backward and require him to announce when he is vertical (head up), when he is tilted backward at an angle of 45° from the vertical, when at an angle of 60°, when at 90°, when at 180°. Two classes of illusions will be found; angles of less than 40° will seem too small; those from 40° to 60° will be rightly judged; those beyond 60° will seem too large. The subject will probably say that he is vertical, head downward, when he is yet 30–60° from it.

SENSATION OF ROTATION.

Apparatus.—Rotation Table. This can be made well enough for the experiments given by laying a 7-foot board across an ordinary turning chair or screw stool without a back. The last must turn without appreciable noise or jar. Many of these experiments could be made perfectly well by twisting the ropes of an ordinary swing.

34. Lay the board across the stool and let the subject be seated upon it with closed eyes and blindfolded if necessary. Turn the stool slowly and evenly in one direction or the other. The subject will immediately recógnize the direction and approximately the amount of rotation when the rate is as slow as 2° per second, or even slower. After continued rotation at a regular rate the sensation becomes much less exact or entirely fails. This fact has been generalized by Mach in the law that only change of rate, not continuous rotation is perceived. With an exception in the case of uniform rates for short times, this is accepted by Delage. After some pauses and short movements in one direction and the other, the subject may become quite lost and give a totally wrong judgment of the direction of motion, if it is slow.

35. Let the subject be seated as before. *a.* Rotate him a little more rapidly for half a turn, and then stop him suddenly. A distinct sensation of rotation in the opposite direction will result. *b.* Repeat, and when the illusory rotation begins, open the eyes. It immediately ceases. Close the eyes again and it returns.

36. *a.* Repeat experiment 35 *a*, letting the subject give the word for stopping. At the same instant let him incline his head suddenly backward or forward or lay it upon one shoulder or the other. The axis of rotation of the body will appear to change in a direction opposite to that of the inclination of the head, i. e., if the head is inclined to the right, the axis, seems to incline to the left. The feeling is as if the body were rotating in the surface of a cone in a direction contrary to that of the first rotation. The head dictates the apparent axis of rotation. The same illusion occurs if the head is inclined during the actual rotation and straightened at the word for stopping. Turning the head to right or left introduces no such illusions, because it does not change the axis of rotation of the head. The illusion comes out with very disagreeable strength when the rotation is rapid and the subject changes the position of his head during the rotation. *b.* Let the subject lie upon his side and rotate him rather rapidly till the sensation of rotation becomes faint or disappears. Then let him turn suddenly upon his back or upon his other side. The first brings the rotation about a new axis, and it is felt in its true sense, while the rotation about the previous axis is felt in its reverse sense; the second reverses the direction of motion completely and produces a correspondingly powerful sensation.

The change of the apparent axis of rotation with the change of position of the head points to the location in the head of the organ by which such sensations are received. For the experiments by which the semicircular canals are indicated as this organ see the literature cited below.

37. Another illusion of rotation (Purkinje's dizziness) is due to the

motion of the eyes. Let the subject whirl rapidly on his heels with his eyes open till he begins to be dizzy; while he whirls the objects about him will seem to be turning in the opposite direction. Let him then stop and look at an even surfaced wall while the experimenter carefully observes his eyes, picking out a fine blood-vessel, or some other clearly marked fleck or spot as a point at which to look. To the subject the surrounding objects will seem to continue to move in the same direction as before, i. e., in a direction contrary to his previous rotation ; the experimenter will see the subject's eyes executing slow motions in one direction (in the direction of the original motion of the subject) alternating with rapid motions in the other. The subject himself may be able to perceive a corresponding irregularity of motion in the spots upon the wall at which he looks. The illusion rests upon the subject's unconsciousness of the slow motions of his eyes. It is not improbable that these eye motions and the sensations of attempted restoration of equalibrium in other parts of the body are reflexly caused by the disturbance in the semicircular canals. It should be noticed that this illusion is the exact reverse of that found with closed eyes in Ex. 35. There the subject feels a rotation of his own body contrary to that it previously received. If he was turned at first in the direction of the hands of a watch, on being stopped he would seem to be turning in a direction contrary to the hands. If these motions were transferred to objects about him, they would, during the rotation, seem to move contrary to the hands and after stopping in the direction of the hands. In the Purkinje experiment the motion of objects is not thus reversed.

SENSATION OF PROGRESSIVE MOTION.

39. So far as progressive motions do not partake of rotation the sensations which they give us are probably combinations of sensations from several different sources or sensory judgments based thereon. For them, as for the motions of rotation, the principle holds that we perceive changes of rate of motion, and not uniform motion; as long as the motion remains uniform we can by an effort of imagination conceive ourselves to be moving in either direction or to be standing still, except for the jarring. The apparatus for the study of these phenomena will be found in railroad trains and elevators.

On the sensations of this and the preceding sections, cf. Aubert, translation of Delage above cited ; Mach, Bewegungs-Empfindungen, Leipzig, 1875; Brown, On Sensations of Motion, Nature, vol. XL., 1889, p. 449, ff.

MUSCLE SENSE, *Kraftsinn.*

The real muscular sensations are probably those of pain, fatigue and the like, and are of relatively minor importance for psychology, but the term "muscle sense" has been used to designate that sense by which lifted weights are perceived, and is here used in that sense.

Apparatus. Set of test weights somewhat like those used for the pressure sense, but less different one from another, (For example: 100 grams (two of this weight), 101.6, 102, 102.2, 102.5, 102.8, 103,3). Weight of 2 or 3 kg.

39. Discriminative sensibility for lifted weights. *a.* Let the subject stand at a table of convenient height. Place within easy reach of his right hand, and near together, one of the standard weights (*e. g.* 100 gm.) and a weight to be compared with it, either the other standard or a heavier (or lighter) one. Let the subject lift one after the other, taking care to lift them in the same way, at the the same rate and to the same height, and give a decision as to which is the heavier (or the lighter). Find the weight that can be distinguished from the standard in 75 per cent. of the trials. As before the ratio between the difference of these and the standard is the index of the discriminative sensibility. The ratio will probably be about 2.5 : 100. *b.* Repeat the experiment letting the subject lift with one hand the standard and with the other

the weight to be compared, keeping the same hand for each during each series of trials. Note the discriminative sensibility as before; the discriminations will be much less fine.

In these experiments the sense of pressure might be expected to co-operate, but when it is excluded or put at a relative disadvantage, the sensibility for differences of lifted weights is not diminished. Weber's method of excluding the pressure sense was to wrap the weights in pieces of cloth and lift them by the four corners together. The pressure on these corners can be changed at will irrespective of the heaviness of the weight lifted. Compare the descriminative sensibility found for pressure with that found for lifted weights.

40. Careful experiments on the method of such discriminations shows that the determining factor is the rapidity with which the weight rises as it is lifted. The following experiment is one of those upon which this conclusion rests. After having performed the second part of Ex. 39, compare the standard weight with a very much heavier weight, *e g.*, 2 kg., with all the circumstances of actual careful judgment. Practice this judgment thirty times, leaving a larger interval of time between the individual comparisons than between liftings of the weights compared. Then at once return to the smaller weights, giving the standard to the same hand as before and the weight to be compared to the hand that has just been lifting the 2 kg. Not only will the weight before just recognizably heavier seem considerably lighter than the standard, but also still heavier weights will seem so. This time the tests must be few, not more than three or four. If more should be desirable, practice the comparison, of the standard and 2 kg. weight again ten times before taking them. By the practice the nervous centres discharging into the the muscles that raise the 2 kg. weight become accustomed to a larger discharge than that required for the small weights and do not at once re-adapt themselves, but supply too great a discharge, the weight rises with greater rapidity than the standard and is consequently pronounced lighter.

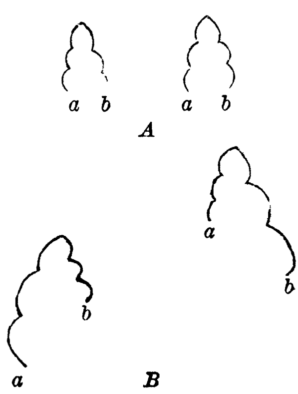
Cf. on Muscle Sense. Weber, *op. cit.*; Müller und Schumann. Ueber die psychologischen Grundlagen der Vergleichung gehobener Gewichte, Pflüger's Archiv, Bd. XLV, 1889, pp. 37–112; James, Psychology, II, pp. 189 ff.

Cf. also the experiments and references on the Psycho-physic Law.

INNERVATION SENSE.

Apparatus. Black board and chalk.

41. The evidence most frequently offered in support of this sense is clinical and therefore beyond the scope of this course. Experiments like the following have been brought forward, but their interpretation has been disputed. *a.* Stand erect before the black board with the eyes closed and coat off, if it interferes with free motion of the arms. Draw with each hand a conventional leaf-pattern like those in the annexed cut drawing from *a* to *b* in both cases. In drawing try to make the lobes of the leaf of equal size, like those in Fig. *A*; draw each with a single simultaneous "free hand" motion of the arm, that is, draw each with a single volitional impulse directed equally to the two sides—the last point is important. First draw a pair of leaves beginning them with the hands before the shoulders at the same height; the result will be approximately like fig. *A*. Next draw a pair with one hand about a foot lower than before; the result will be like Fig. *B*. *b*. Bring the hands again



to the position used in drawing fig. *A*, and draw a pair of leaves having their apices right and left. The leaves will be symmetrical. Next begin with one hand about a foot farther away from the median plane than before and the other at it, but both at the same level. Draw as before; asymmetrical leaves will be the result. Repeat the drawing a number of times, sometimes raising or extending one arm, sometimes the other. In general it will be found that notwithstanding the intention to make equal movements of the hands, the motions of further extension in the extended arm and of further flexion in the flexed arm are too short and those in the contrary direction in each case too long. The argument founded on this experiment runs as follows: We think that our hands execute equal movements, when they do not, because we are conscious of willing equal movements, and unconscious or only inexactly conscious of those actually made. If on the contrary we perceive motion of members by the skin, joint and muscle sensations that accompany their motion (as the opponents of the Innervation Sense believe) we ought to know the extent to which our hands are moved each time and not fall into the illusion that we find in these experiments.

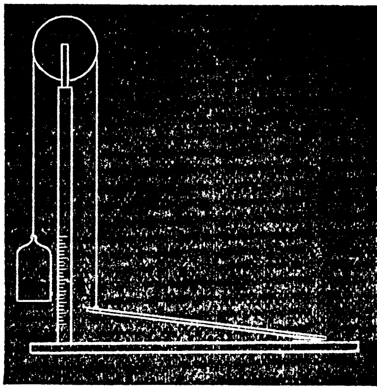
42. Lay the hand palm downwardon the edge of the table or on a thick book so that the last three fingers shall be supported and held extended while the thumb and first finger remain free. Bend the first finger considerably at both the inner joints, and hold it in position with the other hand. The finger tip is still movable as will be found on touching it, but it is anatomically impossible to move it voluntarily. When, however, the effort is made to move it (the eyes being closed) there is a sensation of motion, though no actual motion is possible.

43. Of experimental evidence against the Innervation Sense there is more. Müller's experiment (No. 40) seems conclusive against it; for if there were any sensation of nervous discharge, we ought to know that when we go from a very heavy to a light weight the discharge is disproportionate; but we do not. That the feeling of effort is of peripheral and not central origin is shown by such experiments as this of Ferrier's. *a*. Hold the finger as if to pull the trigger of a pistol. Think vigorously of bending the finger, but do not bend it; an unmistakable feeling of effort results. Repeat the experiment and notice that the breath is involuntarily held, and that there are tensions in other muscles than those that would move the finger. Repeat the experiment again, taking care to keep the breathing regular and other muscles passive. No feeling of effort will now accompany the imaginary bending of the finger. *b*. Lay the fore-arm entirely relaxed in the scale pan of an ordinary balance (or better still of a spring balance) and put in weights enough to compensate it exactly. Remain with closed eyes keeping the arm relaxed. It will after a little overbalance the compensating weights, showing that at first it was not wholly relaxed. An Inervation Sense, if we had one, ought to prevent such an illusion.

Cf. on the Sense of Innervation, Wundt, Physiologische Psychologie; I, 397, ff.; Sternberg, Zur Lehre von den Vorstellungen über die Lage unserer Glieder, Pflüger's Archiv, XXXVII, 1885, 1. Loeb, Untersuchungen über die Orientirung im Fühlraum der Hand und im Blickraum, Pflüger's Archiv, XLVI, 1—46, (but see also criticisms of James, Psychology, II, 516, and of Christine Ladd Franklin, Amer. Jour. Psy., II, 653); James, Psychology, II, pp. 486, ff.; Ferrier, Functions of the Brain, pp. 382 ff., (English Ed.); Funke, *op. cit.*

SENSATIONS OF MOTION, (*Joint Sense*).

Apparatus. Hinged board for passive flexion of the elbow. The accompanying cut will give some idea of the construction of such a board. The thin board on which the fore-arm rests (50 cm. long by 8-10 wide) is hinged at one end to the base board. At the other end a cord is fastened that runs over a pulley upon the top of a stout post. On the end of the cord a weight is hung to counterbalance the weight of the fore-arm. A scale (*e. g.* a piece of mm. paper) on the post near the weight enables the experimenter to read off the distance which the end of the arm-board is raised or lowered. It is essential that the hinge and pully work easily and without jar. The above is simply one way of accomplishing the result; others will occur to those for whom this construction is inconvenient.



44. Passive flexion at the elbow. Let the subject rest the fore-arm flat upon the arm board, bringing the elbow over the hinge, and close his eyes; raise the fore end of the arm-board slowly by pressing down upon the counter weight, and require the subject to announce when he first perceives the *motion* of his fore-arm. It is extremely important not to mistake the sensation of increased pressure or of jar for that of motion. With the dimensions given above, one degree of angle corresponds to about 8.7 mm. The same apparatus may be used for extension as well as flexion.

45. Active flexion of the last joint of the finger. The joint sensations of the fingers are less fine than those of the elbow, but are more convenient for demonstration of active flexion. Fasten a piece of straw, with court-plaster or otherwise, to the finger nail of the middle finger, and cut it off at such a length that the distance from the joint of the finger to the end of the straw shall be 115 mm. With that radius 2 mm. corresponds to about 1° of angular measure. Rest the hand on a thick book letting the last joint of the finger extend beyond the edge. Set up a millimeter scale at right angles with the straw. Close the eyes and make the least possible flexion of the finger at the last joint, having an assistant note its extent on the scale. Between one and two degrees will probably be the least possible voluntary movement. Close attention will, probably in both these cases, locate the chief sensation in the joint. For the more rigorous experiments required to show its character clearly and to prove its location see the following:

Goldscheider, Untersuchungen über den Muskelsinn. Du Bois-Reymond's Archiv, 1889, pp. 369 ff. and 540, also Supplement-Band, 1889, 141 ff.

SENSATIONS OF RESISTANCE.

Apparatus. Two or three kilogram weight and string. Vessel of mercury.

46. *a.* Hold the weight by the string so that it hangs a few inches above the floor, with the arm extended. Lower the weight rather rapidly till it rests on the floor. As it strikes, an illusion of resistance to further motion will be perceived. This is due to the unexpected strain put upon the muscles that lower the arm by the tension of those that have been holding the weight. The feeling of resistance is probably a

joint-sensation. *b*. Something similar is observed on pouring a quantity of mercury from one vessel to another.

Cf. Goldscheider, *op. cit.*

BILATERAL ASYMMETRIES OF POSITION AND MOTION.

Apparatus. Two medium sized corks. A millimeter scale at least one meter long. This can easily be made by pasting millimeter paper upon a smooth wooden slat. A convenient scale has a right angled triangular section. In use this stands upon the short side of the triangle, the long side is next the subject, the hypothenuse next the observer. The millimeter paper is pasted along the upper edge of the side next the observer.

47. Apparently symmetrical positions of the two arms. Hold a cork between the thumb and first two fingers of each hand. Close the eyes and bring the two corks together at arms length in the median plane before the face, having an assistant note the approximate amount and direction of the error. The corks should be brought together rather gently so as not to betray the character of the error to the operator, but the motions of the arms by which they are brought up nearly to contact should be free and sweeping. The error will probably be found rather constant in direction until the operator learns to correct it. Try bringing the corks together above the head, and also in asymmetrical positions.

48. Let the subject seat himself at a table with the millimeter scale before him. Set a pin in the middle of the scale and bring the pin into the median plane of the subject and make the scale parallel to his frontal plane. Let the subject place his forefingers on either side of the pin, and with closed eyes, try to measure off equal distances by moving each outward along the scale. Note the result in millimeters; for this it may be convenient to mark the middle point of the finger-nails with an ink-line. A constant excess in the motion of one hand or the other will be found. It is important that the subject should not open his eyes till his fingers are removed from the scale; for he will find it difficult not to correct his error if he knows its nature. The finger tips should rest lightly on the scale and the motions should be made by a single impulse; if they are too slow and the subject attends to his sensations of position, the errors will be small and uncertain. The greatest errors will probably be found for distances of 20 to 50 cm. from the median plane. The left hand generally makes the greater excursion in right handed persons not mechanics. *b*. Repeat the tests having the motions of the hands made successively instead of simultaneously. The constant difference between the hands will not appear. *c*. Operate somewhat as in *a*, but this time let the experimenter move one of the subject's hands passively while the subject himself tries to move the other at the same rate and to stop instantly when the passive motion stops. Try passive motions of the right as well as the left hand. The errors found will generally resemble those of *a*. *d*. Let the subject start with his right or left hand 20 cm. toward its own side of the median plane, and try to measure off equal distances on either side of that point, using the same hand for both distances. Indicate the point of departure with a pin as before and mark off with another the standard distance to be reproduced. Distances outward will be made too large, distances inward too small. In all these experiments with closed eyes we seem inclined to judge distance rather from the intention of equal motion and the continuance of motor sensations for equal times than from the actual peripheral sensations.

Cf. Hall and Hartwell, Bilateral Asymmetry of Function. Mind, Vol. IX; Loeb, Pflüger's Archiv, XLI, 1887, pp. 107–127, also Pflüger's Archiv, XLVI, 1890, pp. 1–46.

(*To be Continued.*)